Power Distribution Limits

3.0 Objectives

3.1 Define the following terms
3.1.1 Shutdown Margin
3.1.2 Nucleate Boiling
3.1.3 Departure from nucleate boiling
3.1.4 Departure from nucleate boiling ratio
3.1.5 Power Density (linear heat rate)
3.1.6 Axial Flux Imbalance
3.1.7 Heat Flux Hot Channel Factor
3.1.8 Enthalpy Rise Hot Channel Factor
3.1.9 Quadrant Power Tilt
3.2 State the bases for requiring a shutdown margin
3.3 Explain why the required rod index increases with reactor power
3.4 Explain why an ejected rod is worse at high power than low power
3.5 List the 5 emergency core cooling criteria
3.6 Discuss the effect on DNBR from changes in the following parameters
3.6.1 Reactor Coolant Pressure
3.6.2 Reactor Coolant Temperture
3.6.3 Reactor Coolant Flow
3.6.4 Reactor Power Level

4.0 Presentation

4.1 General Introduction
4.1.1 Must generate enough heat to produce desired turbine output
4.1.2 Must ensure that heat generation does not threaten the safety and health of the public
4.2 Public Protection
4.2.1 Protection must be provided during transients and accidents
4.2.2 Barrier concept is used during transients (anticipated operational occurrences).
4.2.2.1 Cladding - RCS - Reactor Building
4.2.2.2 If cladding remains intact then the other two barriers will not be challenged during transients
4.2.2.3 Anticipated Operational Occurrences - . . . *those conditions of normal operation which are expected to occur one or more times during the life of the nuclear unit and include but are not limited to a loss of power to all recirculation pumps, tripping of the turbine generator set, isolation of the main condenser, and loss of offsite power.*
4.3 Operational Limits
4.3.1 Operational Limits are imposed to ensure protection during both transient and accidents
4.3.2 During AOOs, specified fuel design limits must be satisfied.(GDC10)
4.3.3 Specified fuel design limits are:
4.3.3.1 Departure From Nucleate Boiling Ratio
4.3.3.2 Linear Heat Generation Rate
4.3.4 The reactor is required to be shutdown by atleast 1% during both accidents and transients
4.3.5 Accident Limits ensure a maximum degradation of the cladding barrier is not exceeded

4.3.6 Accident Limits

- 4.3.6.1 Ejected Rod limits
- 4.3.6.2 LOCA Limits

4.4 Shutdown Margin

4.4.1 Definition - *the instantaneous amount of reactivity by which the reactor is or would be subcritical from its present condition assuming:*

- *4.4.1.1 No change in APSR position*
- *4.4.1.2 Most reactive rod is stuck out*

4.5 Shutdown margin requirement

4.5.1 Bases

- 4.5.1.1 Ensures that the reactor can be made subcritical from all operating conditions
- 4.5.1.2 Controls postualted reactivity transients
- 4.5.1.3 Prevents inadvert~~a~~ent criticality from shutdown condition

4.5.2 Shutdown Margin Reactivity Calculations - Modes 3-5

- 4.5.2.1 Cover reactivity summation

4.5.3 Shutdown Margin Calculations - Operating

- 4.5.3.1 The utility needs to ensure that the reactor is shutdown when a trip signal occurs
- 4.5.3.2 When the reactor trips reactivity is added by three different coefficients
  - (a) Control Rods - negative reactivity
  - (b) Doppler Coefficient - positive reactivity
  - (c) Moderator Temperature Coefficient - positive reactivity
- 4.5.3.3 If (b) and (c) = (a) then the reactor will not be subcritical

Note - this may be difficult for a begining student to understand. One way to get this point across is to state that it is possible to dilute the plant to criticality with all rods inserted. (This is possible during first cycle).

- 4.5.3.4 Rod Worth - Total available is 11.69%
- 4.5.3.5 Most reactive rod is assumed to stick out - most reactive rod = 3.29%
- 4.5.3.6 Cover shutdown margin for operating condition
  - (a) Doppler + MTC = +1.35 %
  - (b) 0.9(Total rod worth - stuck rod) = -7.56%
  - 1.35 (c) -7.56 + ~~1.15~~ + 1% = -5.21%
  - (d) Numbers from Table 4.3-3 WNP1 FSAR
- 4.5.3.7 Point out that the higher the power, the more doppler will add when the reactor trips
  - (a) Typical value for Power Coefficient = -1E-2
  - (b) reactivity added from 20% = .2%
  - (c) reactivity added from 100% = 1.0%
  - (d) b and c mean more rod worth is required for shutdown from higher powers
- 4.5.3.8 Explain shutdown margin rod index curve

4.6 Ejected Rod

4.6.1 An ejected rod is a rapid reactivity excursion

4.6.2 Because a 1% shutdown margin is required when the reactor is shutdown, a rod ejection from subcritical conditions will not cause a reactivity excursion. BAW-10122

4.6.3 Rod ejection studies start from a critical condition

4.6.4 In order to make the reactor critical, rods are withdrawn

4.6.5 To limit the worth of an ejected rod (and to make the results of the analysis acceptable), rod position is limited:

- 4.6.5.1 Worth of a single rod during zero power will not exceed 1% (zero power = .1%)
- 4.6.5.2 Worth of a single rod at full power will not exceed 0.65% (full power = 102%)
- 4.6.5.3 rod is assumed to add all of its reactivity in 0.10 seconds
- 4.6.5.4 Numbers are from section 15.4.8 of WNP1 FSAR

4.6.6 Analysis Results

- 4.6.6.1 Zero Power Case
  - (a) No DNB
  - (b) Peak power of 82.9%
  - (c) RCS pressure = 3037 psig
  - (d) 3125 is emergency RCS pressure limit
- 4.6.6.2 Full Power Case
  - (a) 5% of rods experience DNB
  - (b) Peak power = 135.1%
  - (c) RCS pressure = > 2500 psig
- 4.6.6.3 Ejected rod is worse at higher powers because the higher thermal power causes DNB and fuel pin failure is assumed.
- 4.6.6.4 Cover ejected rod rod index limits

4.7 Linear Heat Rate

4.7.1 Definition - the power produced per linear foot of fuel height expressed in kW/ft.

- 4.7.1.1 actually a power density expression since each foot of height has both width and depth

4.7.2 Limits are placed on kW/ft for the following reasons:

- 4.7.2.1 Prevent centerline fuel melting during AOOs
- 4.7.2.2 To limit power density prior to LOCA

4.7.3 Centerline fuel limits

- 4.7.3.1 Fuel melts at 5000F to 4800F depending upon time in core life.
- 4.7.3.2 As fuel heats up, fission gasses are released and the cladding could rupture from excessive pressure
- 4.7.3.3 Molten fuel + additional temp can also lead to excessive pressures.
- 4.7.3.4 Regardless of the mechanism, cladding barrier is lost.
- 4.7.3.5 Limit is 20.9 kW/ft.
- 4.7.3.6 Part of the basis for the flux/delta flux/flow trip

is based on kW/ft

4.7.3.6 Avg kW/ft is 5.83 - localized kW/ft is dependent upon:
(a) Total Power
(b) Radial Power Peaks
(c) Axial Power Peaks

4.7.4 kW/ft LOCA Limits

4.7.4.1 During a LOCA, some cladding damage will occur

4.7.4.2 The cladding that is damaged will depend upon the decay heat production in the fuel.

4.7.4.3 The decay heat production depends upon the amount of local fissioning or kW/ft.

4.7.4.4 Cover the LOCA Acceptance Criteria on page 2.2-4

4.7.4.5 Offset (Imbalance Limits)
(a) Definition of imbalance - top flux -bottom flux
(b) offset = power imbalance/total power
(c) more ~~offset~~ is allowed in the bottom of the core because the bottom will recover first.

4.7.4.6 APSR positions
(a) Prevent overpowering the center of the core

4.7.4.7 Linear Heat Rate rod index limits

4.8 Combined Rod Index Limits

4.8.1 Combines SDM, Ejected Rod, and LOCA limits

4.9 DNBR

4.9.1 Cover boiling regime

4.9.2 Define nucleate boiling

4.9.3 Define DNB

4.9.3.1 Bubbles cover cladding

4.9.3.2 Flow oscillations

4.9.3.3 *Operation above the boundry of the nucleate boiling reginme could result in excessive cladding temperatures because of the onset of DNB and the resultant sharp reduction in heat transfer coefficient. Inside the steam film, high cladding temperatures are reached, and a cladding-water (zirconium-water) reaction may take place. This chemical reaction results in oxidation of the fuel cladding to a structurally weaker form. This weaker form may lose its integrity, resulting in an uncontrolled release of activity to the reactor coolant.*

4.9.4 Define DNBR

4.9.4.1 W3 = 1.30

4.9.4.2 BWC Correlation = 1.14

4.9.4.3 DNBR @ 100% = 2.13

4.9.5 DNBR Variables

4.9.5.1 Pressure

4.9.5.2 Temperature

4.9.5.3 Flow

4.9.5.4 Power -3D power

4.10 Peaking Factors
- 4.10.1 Radial Peaking Factor
  - 4.10.1.1 Definition - the avg heat flux in the hot channel divided by the average heat flux in all core channels
  - 4.10.1.2 Accounts for lack of a perfect cosine distribution
  - 4.10.1.3 Maximum Value = 1.25
- 4.10.2 Axial Hot Channel Factor
  - 4.10.2.1 Definition - maximum heat flux/avg heat flux of the hot channel
  - 4.10.2.2 Accounts for differences in axial flux
  - 4.10.2.3 Typical value = 1.47
- 4.10.3 Nuclear Enthalpy Hot Channel Factor
  - 4.10.3.1 Definition - the ratio of the integral of linear power along the fuel rod with the minimum DNBR/ average integrated fuel rod power
  - 4.10.3.2 Accounts for differences in bundle flow
  - 4.10.3.3 Typical Value =16 kW/ft in top of the core
- 4.10.4 Quadrant Power Tilt
  - 4.10.4.1 Definition = 100((power in any quadrant/avg quadrant power)-1)
  - 4.10.4.2 Accounts for minor rod misalignments
  - 4.10.4.3 Typical limit=4.92

4.11 Key Parameters
- 4.11.1 If the following parameters are maintained, then the peaking factors should be within limits:
  - 4.11.1.1 Rod Index Limits and Rod Alignment
  - 4.11.1.2 APSR Index Limits and alignment
  - 4.11.1.3 Imbalance limits
  - 4.11.1.4 Quadrant Power Tilt